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# *Research Department Report*

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## **MEASUREMENT OF DISPLAY TRANSFER CHARACTERISTICS USING TEST PICTURES**

A. Roberts, B.Eng.



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### Summary

*There are three basic parameters which define the transfer characteristic of monitors: contrast, flare and gamma. Each of these can be measured, with varying degrees of accuracy, by a variety of methods. This Report attempts to clarify the definitions of the terms and to specify methods of measurement which give unique and repeatable results.*

*Test pictures are described which permit measurements to be made precisely and rapidly. The test picture for gamma measurement can be used both subjectively and objectively, and gives results which compare well with those produced by the classical method of making point-by-point measurement of the transfer function. The test pictures for flare and contrast give results which are specific to those test pictures only, these results can be used only for making relative assessments of monitors and cannot be used to make accurate predictions of the colour performance of a monitor.*

**Index terms:**    *monitor; display; gamma; contrast; flare;  
                         measurement; test picture*

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## 1. INTRODUCTION

The accurate measurement of display transfer characteristics is notoriously difficult and requires skill and precision to produce repeatable results. Quite apart from the problems resulting from the use of *insufficiently precise measuring instruments*, errors are usually present in measurement data due to inaccurate setting of the display black level. There is also confusion over the definition of Contrast, whether it is used as a range or a ratio. This Report attempts to clarify the definitions of transfer characteristic, contrast and flare, and describes new methods developed specifically for making rapid measurements by using specially designed test pictures.

## 2. DEFINITIONS: CONTRAST $C$ , FLARE $F$ , AND GAMMA $\gamma$

### 2.1 Contrast $C$

The contrast  $C$  that a display can achieve is usually defined as:

$$C = \frac{L_{max} - L_{min}}{L_{min}}$$

where  $L_{max}$  and  $L_{min}$  are the light output values for peak white and black level respectively. For professional broadcast monitoring displays, peak white  $L_{max}$  is usually specified as a luminance level of  $80 \text{ cd/m}^2$ . For other displays, such as domestic receivers, peak white can be taken as the highest luminance level for which the display is still acceptable, usually in terms of resolution or spot size, without causing damage to the display.  $C$  is frequently called the **contrast ratio** or **contrast value**, whereas it is actually the **normalised contrast range**. In common usage, contrast is frequently quoted as a ratio in the form  $C:1$ . To avoid compounding this confusion,  $C$  is described only as **contrast** in this Report.

The main problem with this definition of contrast is that it is the black level  $L_{min}$  which is used as the normalising agent, and it is in the setting of black level that most practical difficulties occur. Indeed, for measurement of gamma it is normal to raise the black level to about  $0.5 \text{ cd/m}^2$  simply in order that it can be measured, clearly this practice is not acceptable when attempting to measure contrast. In normalising the light levels to  $L_{min}$ , undue importance is given to black level since as  $L_{min}$

becomes vanishingly small (as in good quality displays) the value for  $C$  becomes infinitely large.

For a typical professional cathode ray tube display the value for  $C$  can be expected to exceed 1000; a display with less contrast than 100 will lack 'sparkle' in that its black level will be plainly visible and reproduced colours will be desaturated.

In an ideal world, it might be beneficial to redefine contrast by using a formulation such as:

$$C' = \frac{L_{min}}{L_{max}}$$

and when using this value in a ratio expression the form would be  $1:C'$ , and the value of  $C'$  would become vanishing small as the black level is reduced, thus indicating the true significance of the black level  $L_{min}$ . It is certainly too late to change the widespread usage of the first formulation for  $C$ , and so new formulations for contrast will not be proposed in this Report.

### 2.2 Flare $F$

Flare in a display is not commonly quantified because it is difficult to measure, but can best be defined as:

$$F = \frac{L_{min} - L_{off}}{L_{max}}$$

where  $L_{off}$  is the true black level, excluding flare effects, and  $L_{min}$  is the black level in the presence of flare-inducing peak white  $L_{max}$ . Again,  $L_{max}$  is the peak white luminance, either  $80 \text{ cd/m}^2$  for professional displays or the highest brightness achievable before the onset of resolution loss.

Flare thus defined is directly related to contrast by a simple relationship:

$$F(C + 1) = 1 - \frac{L_{off}}{L_{min}}$$

which does not include  $L_{max}$ . Knowledge of  $L_{max}$  is needed in order to calculate either flare or contrast directly from the measurements, but this relationship can be used to calculate either flare or contrast from the other. If  $L_{off}$  is zero (as is usually the case) then the relationship can be further simplified:

$$F(C + 1) = 1$$

Flare is a function of many variables; it depends on the cathode ray tube glass transmittance and reflectance, the ratio of screen size to glass thickness, reflectance of the light-producing phosphors, and not least upon the test signal and the instrument used to measure it. Nevertheless, this definition of flare is useful as a parameter for comparisons between displays. The definition includes neither the optical effect of flare in the observer's eye lens, nor the psychovisual depression of black level when in the presence of peak white or other bright signals; since these effects are more to do with the observer than the display, they are beyond the scope of this Report.

### 2.3 Gamma $\gamma$

The transfer characteristic of a display device is defined as the relationship between the modulating electrical drive signal  $V$  and the resultant light output  $L$  of the display. Ideally, when the drive signal is at zero, the light output is also at zero, but this condition is rarely met due to a variety of causes such as stray light and electrical offsets within the display device itself as discussed above. For some types of display the relationship will follow a curve which cannot be characterised by any simple form of equation, but for the cathode ray tube there is a simple power law which relates output to input:

$$L = kV^\gamma$$

where  $k$  is a constant and  $\gamma$  characterises the display.

Historically, the value of  $\gamma$  has been thought to be about 2.8 for typical cathode ray tube displays, but measurement and calculation techniques have not been sufficiently accurate to produce reliable results until recently. Measured data have deviated from the power law curve when near black level, and explanations of this deviation have included statements such as 'the power law does not hold near black'. Recent measurements made using a new mathematical technique<sup>1</sup> to quantify and eliminate the offsets in the equation have shown that the power law extends down to light levels which are difficult to measure, and thus no theoretical explanation is needed to excuse deviations from the power law.

## 3. MEASUREMENT METHODS

Measurements must be made in a darkened room to avoid the effects of stray light, and the display must be allowed sufficient time to warm up before measurements are made. Cathode ray tube displays usually exhibit rapidly changing characteristics during warm-up, particularly in black level setting, and the display should not be expected to be fully stable until

the entire display apparatus has reached thermal equilibrium which can take up to one hour. Even when thermal equilibrium is reached, domestic displays may still be unstable if the power supply regulation is inadequate or if the black level clamping circuit is not properly controlled.

### 3.1 Contrast measurement

Contrast measurement can be made in two ways, either excluding or including the effects of flare. If measurement is made on the black and white levels within a test picture containing both peak white and black levels simultaneously, then flare from the white areas will affect the black areas. This may seem to be a realistic indication of contrast, but it is representative only of contrast for that test picture and for the measurement sites used on the display screen. Such a method can be used to rank-order several displays by indicating the relative performance, but will not provide data which can be used for accurate mathematical modelling of the display for other pictures. For mathematical modelling, an absolute method is required which both quantifies flare and eliminates its effect from the measurement of contrast, unfortunately such methods are impractical at present. It is not possible to measure displays with sufficient precision to fully characterise them in terms of contrast; the best that can be done is to make measurements on test pictures which, in themselves, are designed to be typical of real pictures, and to use these results as an indication of display performance.

The methods described below show how the relevant light levels can be measured. Measurements must be made in a darkened room to avoid the effects of stray light and the display must be allowed sufficient time to warm up before measurements are made. Two techniques are described, both require the use of two test pictures.

#### 3.1.1 Inter-picture measurement of $L_{off}$ and $L_{max}$

This method is designed to eliminate the effects of flare from the contrast measurement by using two test pictures, one to establish the true black level  $L_{off}$  and another to establish the peak white  $L_{max}$ . True black level, for this purpose, is defined as the low-light level at which modulation by a small-amplitude video signal is on the verge of extinction in the absence of flare-inducing white signals. White level for measurement of studio quality monitors is defined as 80 cd/m<sup>2</sup>, for other displays it can be taken as the highest light output level which can be achieved without loss of resolution or damage to the display. Thus,  $L_{off}$  (and possibly  $L_{max}$ ) is set subjectively by the

observer, but measurements are made objectively using a calibrated light meter.

This setting and measurement method using two test pictures cannot be used on displays which do not exhibit highly stable black levels, thus it is unsuited to measurement of normal domestic displays.

The first test picture, used for setting and measurement of peak white, must not illuminate the whole display, such a signal could cause power supply regulation problems and overheating of the shadow mask in a colour cathode ray tube. A suitable signal is based on that recommended by the EBU for the measurement of white uniformity<sup>2</sup>. This signal illuminates nine circular measurement sites and is shown in Fig. 1 where the measurement sites are at peak white (700 mV) and the background is at black (0 mV). This test pattern is readily applicable both to conventional 4 : 3 aspect ratio displays and to the newer 16 : 9 displays. Only the central site is needed for setting and measuring peak white  $L_{max}$ , measurement at the other sites would give data for white uniformity calculations. The measurement sites are shown as circular with a diameter of 0.1 H, and are placed with number 1 centrally, numbers 2 to 5 symmetrically placed about the centre on a circle of 0.4 H radius, and numbers 6 to 9 symmetrically placed from the centre at distances of  $\pm 0.4 W$  horizontally,  $\pm 0.4 H$  vertically.

In practice, the sites need not be precisely circular and may need to be rather larger than 0.1 H in order to fully illuminate the light meter, unless a focusing spot-meter is used. In any case the sites should not be unnecessarily large since the use of larger patches may cause unnecessary flare from the white patches into the surrounding black areas.

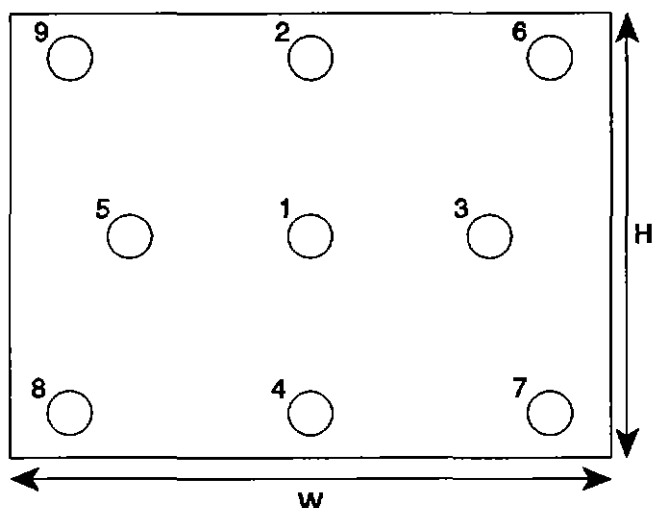


Fig. 1 - Nine measuring sites for contrast and flare.

The second test picture, used for setting and measurement of black level, must not contain any bright parts which could cause flare, and yet the operator must be able to identify the lowest brightness level at which modulation by the video signal can still occur. One way of achieving this is to establish the brightest black level at which *negative* video modulation is *invisible*. This is the technique used in the PLUGE signal for setting black level, but PLUGE is unsuitable since it contains a bright grey-scale which would cause flare. In order to avoid flare altogether, the test signal must contain no elements excusing above black level (0 mV) but must contain low amplitude patterns excusing below black level. For simplicity, the test signal can have the same patterns as that for setting white level shown in Fig. 1, but with the nine measuring sites at 0 mV (black) and the remainder of the picture at a negative level of -2% (-14 mV relative to line-blanking level, sub-black). The operator then can reduce the display black level until the circles are just invisible, and measure the light level of the centre patch as  $L_{off}$ . Ideally this light level should be zero but the precise value will depend to some extent on the measuring conditions; any stray light falling on the display will mask the pattern and cause the operator to increase the black level until the pattern is 'just not visible'.

In practice it will probably be necessary to repeat the setting of black and white levels, as each interacts with the other to some extent.

A value can be found which, for the purposes of this Report, can be called the 'absolute contrast'  $C_{abs}$  achievable by the display, and is defined as:

$$C_{abs} = \frac{L_{max} - L_{off}}{L_{off}}$$

but to quote this value as definitive of the display would be misleading since it does not include the effects of flare and thus  $L_{off}$  should be vanishingly small; however, the measured value of  $L_{off}$  does allow flare to be quantified, as is shown in a later section.  $C_{abs}$  should not be quoted as a measurement result, indeed it may have a calculated value of infinity if the photometer does not register a value for  $L_{off}$ .

The photometer used for these measurements should ideally be capable of resolving more than two decimal places of luminance. For example, a value for  $L_{off}$  of 0.04 cd/m<sup>2</sup>, measured with a photometer having only two decimal places (resolution of 0.01 cd/m<sup>2</sup>), results in a value for  $C_{abs}$  of 2000, but the quantisation of  $L_{off}$  implies an uncertainty of  $\pm 0.01$  cd/m<sup>2</sup> and this means that  $C_{abs}$  is quantised as 1600, 2000 or 2667. Such high values are common in studio monitors and so the effect on the result, due to

the precision of the measurement instrument, must always be borne in mind. Clearly, in these circumstances it would be better to quote the measured value  $L_{off}$  and its measurement tolerance, rather than to have to explain the limitations of its use in a formula.

### 3.1.2 Intra-picture measurement of $L_{off}$ and $L_{max}$

In this method both black and white levels are set using the test signals described above but the effects of flare are included in the calculation of contrast, and no attempt is made to measure the black level  $L_{off}$ . Instead, measurement is made of  $L_{min}$  by taking the average of four measurements, from sites midway between site 1 and each of the four sites on the 0.4 H circle (i.e. sites 2 to 5). This value for  $L_{min}$  thus includes any effects due to flare from the adjacent peak white patches, and the equation for contrast  $C$  is as described above:

$$C = \frac{L_{max} - L_{min}}{L_{min}}$$

Again, this value for contrast can be misleading if the measured values for  $L_{min}$  are very small, and again the effects of quantisation of the measurements must be borne in mind. Thus the very large values for  $C$  which can result from very low values of  $L_{min}$  can be unreliable, and it may be better not to quote  $C$  at all, but to measure and quote the flare  $F$ , since this becomes vanishingly small for low values of  $L_{min}$  and thus is presented in its true significance.

### 3.2 Flare measurement

Measurement of flare  $F$  requires measurements made from both the test pictures described above, and all the observations regarding measurement methods for contrast apply equally to measurement of flare.

$$F = \frac{L_{min} - L_{off}}{L_{max}}$$

Normalisation to peak white ensures that the measurement of flare produces realistically small values, and the subtraction of  $L_{off}$  ensures that the effects of vanishingly small (and inaccurately quantified) black levels are also small.

### 3.3 Gamma measurement

There are two methods available for the measurement of transfer characteristic; the point-wise method is slow to perform but can give highly precise results, the second method uses a test picture to derive only an approximate value for gamma but can be done very quickly.

#### 3.3.1 Measurement by the traditional point-wise method

The display must be highly stable, black level must not change as the signal level is changed during the measurements, and therefore this method is not suited to the measurement of domestic displays.

The traditional method for measurement of cathode ray tube displays is to establish the relationship between drive voltage  $V$  and resultant light  $L$  at several points over the entire contrast range and to construct a correspondence table. Measurements are usually made statically, by attenuating a test signal and measuring the resulting light level, but there are dynamic methods<sup>3</sup> which can measure the slope of the correspondence curve at various brightness levels. The static method is more reliable.

Having first set the display black level, using either a PLUGE signal or the test signal described above for setting black level, the relationship between  $V$  and  $L$  is found by attenuating a test signal such as that described above for setting peak white and measuring the resultant light level. Since a logarithmic relationship is expected, it is sensible to attenuate the signal in steps of 2 or 3 dB. Measurements should be made over the greatest possible range of signal levels, typically 30 dB is the minimum acceptable range, ideally 40 dB or greater should be attempted (for a typical display with a gamma of 2.35 and peak white set to 80 cd/m<sup>2</sup>, 30 dB attenuation produces a light level of 0.024 cd/m<sup>2</sup>, 40 dB produces 0.0016 cd/m<sup>2</sup>), in any case measurements should be made until further attenuation produces no further change in measurable light level.

From these measurements the supposed relationship can be found graphically, assuming it to be of the form:

$$L = kV^\gamma$$

and the value for  $\gamma$  is found by plotting the values for  $L$  versus the corresponding values for  $V$ , both logarithmically, and drawing a straight line through the points. The slope of this line is  $\gamma$ . Even when measurements are carefully and properly made, the data values are likely to contain errors due to noise, inaccurate setting of the black level, and other causes. It would be unusual to be able to draw a straight line through all the points, there is usually some curvature in the distribution of points which precludes accurate fitting of a straight line. However, provided that measurement noise is low and the other errors are stable, i.e. that they do not change during the course of measurement, the errors can be corrected for by using a mathematical technique<sup>1</sup> which estimates the offsets in voltage (black level setting error) and light

(black level setting error, stray light, 'dark signal' in the photometer). This removes data curvature and produces highly repeatable and precise values for  $\gamma$ .

The measurement technique is tedious and difficult to perform and is impractical except under laboratory conditions, but it produces accurate and repeatable results. Experience with this technique has shown that, for cathode ray tube displays, there is no evidence of the power law being inappropriate near black level, although measurement points at very low levels can be unreliable through noise and measurement quantisation.

This method cannot yield an equation for displays which do not exhibit a simple logarithmic relationship between drive voltage and light (liquid crystals, plasma panels, etc.). Other types of more complex equation might be found to characterise these displays but methods for their extraction are beyond the scope of this Report.

### 3.3.2 Measurement by the test picture method

For cathode ray tube displays, which are expected to exhibit the logarithmic relationship described above, another method exists which can find a value for gamma by the use of a single test picture. If, when the black level is accurately set, a drive signal  $V_{grey}$  can be found which produces a mid-grey brightness  $L_{grey}$  having exactly half the brightness of the peak white produced by  $V_{max}$ , then that grey point lies on the line of slope  $\gamma$  which joins black to white when plotted logarithmically, or:

$$\gamma = \frac{\text{LOG}(L_{grey} / L_{max})}{\text{LOG}(V_{grey} / V_{max})}$$

Neither the value of  $L_{max}$  nor  $L_{grey}$  need be measured at all, since  $L_{grey}$  is known to be  $L_{max}/2$ . The value of  $V_{grey}$  which produces  $L_{grey}$  can be found subjectively by matching  $L_{grey}$  to the brightness of a fine pattern of alternating black and white sections in equal proportions which integrate to grey in the eye.

A dedicated test signal can be designed to find the value of  $V_{grey}$ ; one field of an interlaced pair comprises a pattern of alternate lines of black and white and the other field comprises lines of only  $V_{grey}$ , the value of  $V_{grey}$  is adjusted electronically until the display exhibits no visible flicker at the picture frequency and therefore the two fields have the same brightness. The value of  $V_{grey}$  thus found produces a field whose brightness matches that of the other, the average of black and white integrated in the eye. In practice it is much easier to use a test signal containing many patches of such patterns, each prepared with a

different value of  $V_{grey}$  derived from a range of values of  $\gamma$ . The patch which exhibits no (or least) picture-rate flicker yields the appropriate value of  $\gamma$  for the display, under the current viewing conditions.

Experience with such a test signal has shown that increments of 0.1 in the value of  $\gamma$  are suitable and can be distinguished from each other by the average observer. Table 1 shows the values of  $V_{grey}$  in mV, relative to a peak white signal  $V_{max}$  of 700 mV, for a suitable range of values of  $\gamma$ .

Table 1: Values of  $V_{grey}$  for various values of gamma ( $\gamma$ ).

$\gamma$	$V_{grey}$	$\gamma$	$V_{grey}$
2.0	495	2.5	536
2.1	503	2.6	541
2.2	511	2.7	547
2.3	524	2.8	551
2.4	531	2.9	556

Fig. 2 shows a test signal based on these values, which is currently in use at Research Department and elsewhere for assessment of displays. It contains ten test patches of alternate black and white lines on one field and grey on the other, together with alignment aids in the form of a peak white patch and PLUGE-like signals above and below black for the setting of black level. The black level set using this test signal will not be the true black level  $L_{off}$  since optical flare will pollute the black signal as described in Section 2, nor will it be  $L_{min}$  since the flare induced by this test picture will not be the same as that induced by the other test signal described above. However, experiments have shown that for typical displays the resultant value for  $\gamma$  differs by less

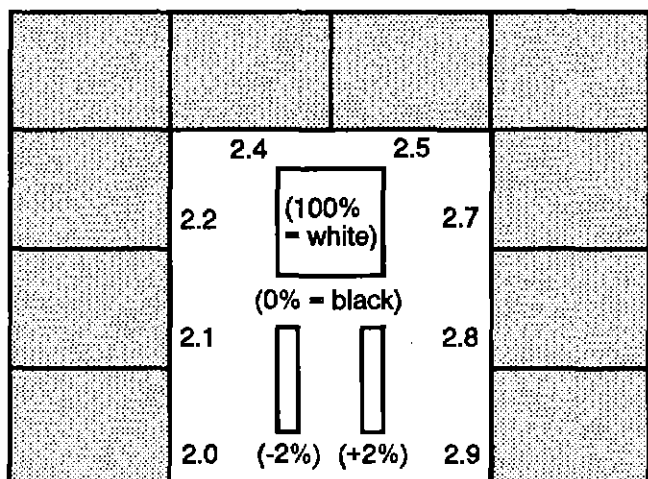
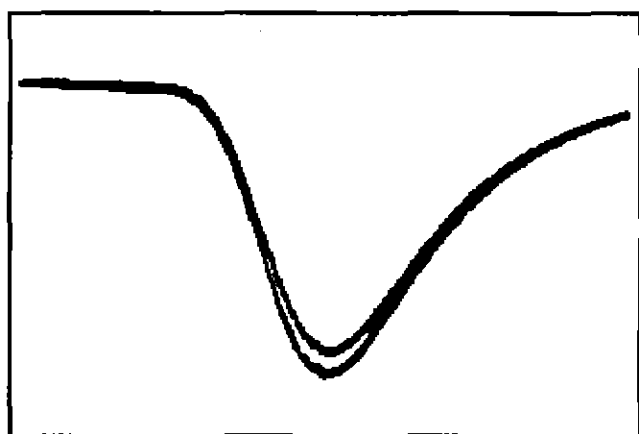
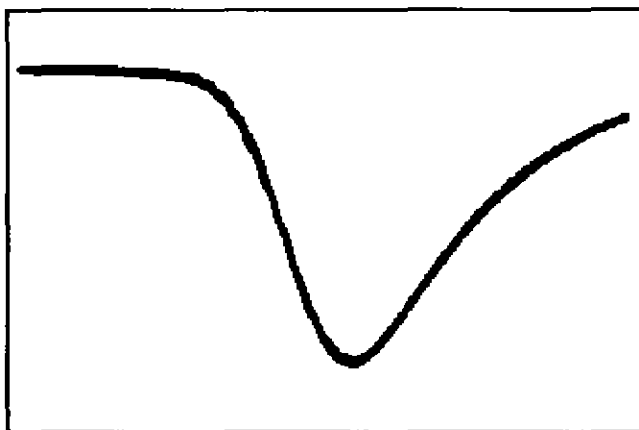


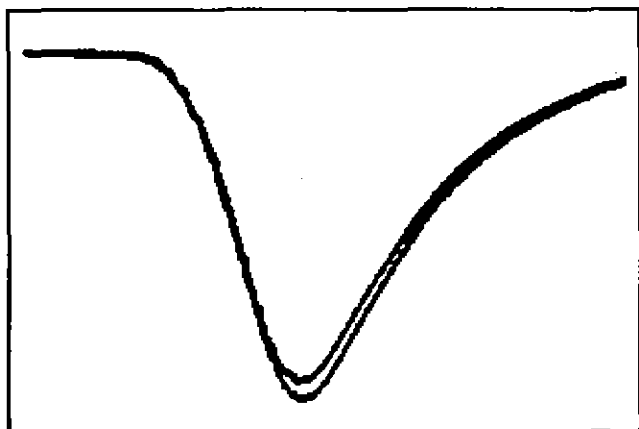
Fig. 2 - Test picture for gamma measurement.



(a)  $\gamma = 2.1$ .



(b)  $\gamma = 2.3$ .



(c)  $\gamma = 2.5$ .

Fig. 3 - Field-rate traces.

than 0.1 from that obtained by the traditional point-wise method, which is less than the quantisation limit set by this test signal.

Since a single test signal is used and instantaneous assessment is made, measurements can

be made of displays which do not have highly stable black levels, such as domestic receivers. The test signal can travel successfully through even low-bandwidth recording systems such as VHS since it contains no essential high frequency components, and it can be applied to a large number of displays such as in a studio gallery for simultaneous assessment.

Using this test pattern, an experienced observer can detect the patch which flickers least with little difficulty. It may be necessary to use the enhanced flicker perception of peripheral vision, by looking away from the patch concerned, but untrained observers have found little difficulty in using the test signal to produce consistent results. An objective version of this technique is possible, using a photometer such as a photocell or photomultiplier as a flicker detector. The photometer is placed over each patch in turn until the electrical output, as observed on an oscilloscope scanning at the field rate, produces the same signal on each field. A low-pass filter is needed to remove the line-rate components, about 1 ms time constant is sufficient. Fig. 3 shows the result of such measurement on a typical domestic receiver; both Figs. 3(a) and 3(c) ( $\gamma = 2.1$  and  $\gamma = 2.5$  respectively) clearly show two separate traces but Fig. 3(b) shows only one trace and this indicates that the display had a  $\gamma$  of about 2.3.

#### 4. RESULTS OF MEASUREMENT OF TYPICAL DISPLAYS

##### 4.1 Contrast and flare

For the purposes of illustration, two typical studio monitors were measured using both test signals, with a photometer which indicated light output in standard units ( $\text{cd/m}^2$ ) but with only two decimal places in its digital output. The results and calculations are shown in Table 2.

Table 2: Measurement results for two typical monitors.

Monitor	$L_{\text{off}}$	$L_{\text{min}}$	$L_{\text{max}}$	$C_{\text{abs}}$	$C$	$F(\%)$
1	0.00	0.08	81.5	$\infty$	1018	0.098
2	0.03	0.09	78.6	2619	872	0.076

This shows the importance of using a high-precision measuring instrument, and the nonsensical results of calculating  $C_{\text{abs}}$  when  $L_{\text{off}}$  is zero (or is indicated as such by a low-precision photometer). The results give the interesting conclusion that monitor 2 has lower contrast than monitor 1 despite having rather lower flare, this being due to the significantly elevated true black level  $L_{\text{off}}$  for monitor 1. One

conclusion which can be drawn from this is that it may be wise to quote the value of  $L_{off}$  (extinction black level) as well as flare  $F$  and contrast  $C$  when attempting to characterise a display. Alternatively it could be argued that absolute precision in such measurements is impossible, and that the two monitors were nominally identical. Certainly, these results were repeatable, although the differences were small.

#### 4.2 Transfer characteristic

A range of conventional professional and domestic displays were measured using the test signal and produced  $\gamma$  values of 2.3 or 2.4. There were no cathode ray tube displays measured with  $\gamma$  values as high as 2.8. These results have been confirmed using the point-wise measurement method described above, with mathematical estimation of offset values<sup>1</sup>.

### 5. CONCLUSION

Simple methods of measuring the contrast, flare and transfer characteristic of television displays have been shown. Three test pictures have been designed and used for these purposes, and

measurements using them have produced consistent and repeatable results.

### 6. ACKNOWLEDGEMENTS

Thanks are due to Nigel Goodship and Martin Gee for their work on test pictures for gamma assessment, and to Richard Salmon for work on contrast and flare measurement.

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